

TECHNICAL MANUAL

**ROOFING
AND
WATERPROOFING**

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HEADQUARTERS, DEPARTMENT OF THE ARMY

MAY 1993

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HEADQUARTERS
DEPARTMENT OF THE ARMY
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ROOFING AND WATERPROOFING

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CHAPTER 1

GENERAL

1-1. Purpose

This manual provides guidance for the design of roofing and waterproofing systems for building construction.

1-2. Scope

This manual covers roofing and waterproofing components and materials. Roofing components include deck, vapor retarder, insulation, membrane surfacing and flashing. Roofing materials include built-up, single-ply, modified bitumen, protected membrane and fluid-applied roofing for low slope roofing, and shingles, shakes, tiles, and roll roofing for steep roofing. Waterproofing and dampproofing systems are also addressed. This manual does not include metal roofing and structural design of roof decks. References are provided for sources of construction details.

1-3. References

Appendix A contains a list of references used in this manual.

1-4. Performance

To perform satisfactorily, roofing and waterproofing must have adequate design, workmanship, and material; and roofing must have periodic preventative maintenance.

1-5. General requirements

Roofing designs must provide an economical system which will withstand years of exposure to the weather and to local conditions such as traffic, oil, grease, or other chemicals. Roofing may have to meet local aesthetic requirements or blend with neighboring buildings. The roof must resist wind and fire; it must slope to drain water off the roof; and it must resist condensation. Roofing usually accounts for less than 10 percent of a building's costs, but may create more than half of the construction complaints, and often falls short of its design life. Roofs designed to last twenty years often require excessive maintenance and sometimes must be replaced after only a few years.

1-6. Fire resistance

The fire-rating required of a roof depends on the building occupancy and other factors not within the scope of this manual. The fire rating is based on external and internal hazards. Generally, the roofing system is rated as an assembly, including all components.

a. External. Underwriter's Laboratories (UL) rates external fire exposure resistance in three classes: "A" (severe), "B" (moderate) and "C" (light fire exposure). Roofing systems for military construction should be Factory Mutual (FM) approved or UL Class A, exceptions should be justified; as for example, a low risk temporary or expendable structure. Built-up roofing (BUR) and modified bitumen roofing which is not fire-rated should be covered with gravel, 3 to 4 pounds per square foot, in a flood coat of asphalt. Other types of membranes may be protected by loose aggregate or a fire-resistant coating. When the roof is not fire rated, the spaces between buildings should be as for asphalt shingle roofing.

b. Internal. A roofing system's internal (below deck) fire resistance is rated by FM as Class I or II. This resistance is especially important for steel deck roofs which can transmit heat from a fire under the deck to components above the deck. The resulting combustible gases, confined by the roof membrane, will penetrate the deck and ignite, thus spreading the fire, possibly through the entire building. FM "Class I" rated decks are noncombustibles such as concrete or gypsum, or steel decks which are covered by non-combustible insulation so that heat released to the roof assembly does not exceed established limits. Bitumen or flammable insulation applied directly to a steel deck will make it ineligible for a Class I rating. Steel deck roofing systems should be approved and listed in the FM Approval Guide. A Class II roof assembly is one which will produce more heat from the materials above the steel deck than allowed by the FM requirements. Class II roof assemblies should not be used without sprinklers.

c. Substitution of Components. Substitution of components or configuration can jeopardize the fire classification of a roofing system. The installed system must be identical in materials and construction to the tested and rated roof system.

d. Parapets. Parapets are not required where roof decks are of heavy noncombustible construction such as concrete or gypsum. For other low slope roof decks, parapets should be as required in section 1709 of the Uniform Building Code.

e. Laboratories. While roofing systems must conform to specified UL and/or FM standards, tests and certifications equivalent to those standards can be performed by any approved qualified laboratory. (Testing by a laboratory equivalent to FM or UL will require special documentation and approval by the Contracting Officer.)

1-7. Wind resistance

Wind resistance requirements for roofing depend on geographic location, local topography, and the height, size

and shape of the building. Requirements will be developed as specified in ASCE 7. Wind resistance must be provided by use of fasteners, adhesives, ballast, or a combination thereof, subject to the following considerations:

a. Roofs are especially vulnerable to wind damage because of their large surface areas. On a low-slope roof there is a negative pressure on the upwind portion and a positive pressure on the downwind portion. For steep roofs, the reverse is true.

b. On steel decks, the bottom layer of insulation must be mechanically fastened. Adhesives are not satisfactory on steel decks.

c. Aggregate ballast may be locally prohibited due to high winds or proximity to aircraft operations. In such areas, the membrane should be reinforced, fully adhered, and insulation should be mechanically fastened. Pavers or large aggregates can provide resistance to very high winds.

d. Loose-laid and ballasted systems cannot be rated for wind resistance. For ballasted systems, designers should follow recommendations of the Single Ply Roofing Institute's "Wind Design Guide for Single Ply Roofing Systems."

e. In high wind areas air seals should be used to keep pressure in the building away from the membrane, and "stretchy" membranes such as ethylene propylene diene monomer (EPDM) should be avoided.

1-8. Slope

Slope is defined as inches of vertical rise per horizontal linear foot, commonly shortened, as for example: the "1/4-inch slope." Roofing must shed water and must be sloped to provide positive drainage. Slope is critical to the performance of a roofing system; a minimum of 1/4 inch slope per foot will be provided. "Low slope" and "steep slope" practices overlap at about 2 inches; that is, some "steep" techniques are used on slopes down to 1 inch while some "low-slope" systems are used on slopes as high as 4 inches. The roof slope should be provided by the underlying structural system. Where provision of slope in the structure is impractical, lightweight concrete or tapered insulation may be used.

1-9. Climate

The effects of climate extremes must be considered when selecting a roofing system.

a. Hot Climates. In hot dry climates, monolithic-concrete structural roof can provide satisfactory roofing with no membrane except at the joints. More often, the concrete is covered with a membrane or insulation and membrane system. In hot humid climates water vapor flows towards the air-conditioned interior, and the roof membrane acts as a vapor retarder, preventing water vapor from entering the underlying insulation. Insulation above the roofing is sometimes used to protect membrane from high temperature and UV exposure in hot climates.

b. Surface. In hot and moderate climates, a light colored surface will reduce temperatures experienced by the roof membrane. This will reduce energy required to cool the building. For this purpose, the coating or aggregate should be opaque to ultraviolet (UV) light to prevent UV degradation of the underlying material. A few membranes do not require surface protection even in hot climates, but long exposure to ultraviolet light and high temperatures will deteriorate most membranes.

c. Cold Climates. In cold climates, roof eaves require special design to prevent or accommodate build-up of ice dams. Moisture within a building will move towards a cold roof. A vapor retarder may be needed to prevent condensation. An effective way to prevent condensation is to use a protected membrane roof (PMR) where the insulation is placed above the membrane. This also helps to isolate the membrane from temperature extremes and from freeze-thaw damage.

d. Cold Weather Application. When temperatures are lower than 40 degrees F. hot bitumens require special precautions such as insulated hoses and kettles. Hot bitumen and adhesives should not be applied at temperatures below the dew point. Some manufacturers provide loose-laid single ply or heat-applied modified bitumen membrane systems which can be applied at low temperatures.

1-10. Moisture migration and vapor retarders

Moisture will condense from warm moist air when it moves to a place that is colder than its dew point. When the movement of the air is stopped by a permeable material, very little moisture will migrate through, even when water vapor can penetrate through the material. However, large quantities of moisture can be transported by a flow of warm moist air. Consequently, while all roof systems should resist air leakage, relatively few need a vapor retarder to stop vapor diffusion. The roofing industry has adopted the term "retarder" rather than "barrier" because almost every material has a measurable permeability to water vapor, and the construction details introduce a wealth of paths for water vapor to bypass the "vapor retarder."

a. Location. Air barriers can do their job anywhere in the roofing system, but vapor retarders need to be placed on the warm side, far enough from cold areas so that condensation will not take place. Since a membrane roof stops the air flow, it is less vulnerable to condensation than a framed roof with permeable below-deck insulation. The ability of the membrane to resist air leakage makes the difference.

b. Need. A vapor retarder may be needed to prevent humid air from condensing on cold building components such as insulation, structures, deck or membrane beneath the roof surface. Condensation of moisture in these areas can negate the insulating effect of insulation, collect water which may leak back into the building interior, and damage structures by corroding metal and rotting wood. A vapor retarder is often specified for a heated building where

January average exterior temperature is below 40 degrees F. and the expected interior winter humidity exceeds 45 percent. A vapor retarder is usually required in cold climates for laundry or swimming pool construction. However, a vapor retarder may not be needed if the area being considered is adequately ventilated.

c. Permeability. Vapor retarder material should have a permeability of less than 0.5 perms.

d. Venting. Ventilation of the insulation layers between the membrane and the vapor retarder is not recommended because water can enter quickly while the resulting moisture is slow to exit. Steep roofs over permeable below-deck insulation generally require ventilation.

e. Hot Climates. In hot humid climates, the roof membrane acts as a vapor retarder to prevent moisture flow inward towards the air conditioned interior. There should be no vapor retarder inside the roof system as it will trap moisture between the vapor retarder and the roof membrane.

f. Dew Point. When a vapor retarder is needed, the location of the dew point must be determined for the design winter exterior-low and interior-high temperatures, and the highest design interior humidity, close to the roof deck. The dew point, inside the membrane, must be on the cold side of the vapor retarder, usually in the insulation above it.

g. Design. The vapor retarder must be completely sealed. All penetrations must be air-tight so that there are no leaks which could carry the water vapor to the cold side of the vapor retarder. Fasteners should not penetrate the vapor barrier, as they are nearly impossible to seal. Steel decks should not be considered as vapor retarders.

1-11. Aesthetics

Roofing design must be compatible with the local environment and with the economic and energy conservation goals of the building. The roof design may be dictated by that of surrounding buildings as part of the installation master plan. In such cases, the designer still has a few options; for

example; where a particular aggregate surface is required, a different membrane may be used beneath the aggregate. Aesthetic considerations also involve energy conservation: light-colored surfaces will reflect more solar energy than dark ones, and in many locations air conditioning is more expensive than heating. Some locations are required to have subdued colors to minimize glare seen by pilots in nearby airfield flight patterns.

1-12. Economics

The life cycle cost of a roofing system is unique for each roof because of variables in the nature and use of the building, the local climate and features of the site. Roofing costs are sensitive to local availability and markets as roofing materials are expensive to transport and product lines are continually being changed. Costs of alternative roofing systems can be compared to the cost of the widely-used four-ply glass-felt and asphalt built-up roofing system (designated here as "asphalt BUR"). A similar 4-ply coal tar pitch system can be expected to be about 10 percent more expensive than the asphalt BUR. Fully adhered ethylene propylene diene monomer (EPDM) single-ply roofing may cost slightly less than asphalt BUR. Loose-laid modified bitumen membranes are comparable in cost to asphalt BUR, but fully adhered modified bitumen may cost half again as much. Other single-ply membranes may cost 1-1/2 to 2 times as much as asphalt BUR. (Aggregate surfacing adds less than 5 percent of the material cost.) Metal roofing will cost 4 to 5 times more than asphalt BUR.

1-13. Details

Roofing, waterproofing and vapor retarder information is provided in the NRCA Roofing and Waterproofing Manual. More information on insulation and vapor retarders is available in the NRCA Energy Manual and TM 5-852-9. Sheet metal details are provided in the SMACNA Architectural Sheet Metal Manual. Manufacturers may also require use of specific details as a condition of warranty.

CHAPTER 2

LOW SLOPE ROOFING

2-1. Introduction

Almost every large building has a low slope roof, a long expected-building life and a negligible roofing maintenance budget. In the past, low slope roof decks were covered with bituminous built-up roofing (BUR) and expected (often optimistically) to last 10 or 20 years. BUR systems have been greatly improved, but remain labor-intensive and require skilled installation. Single-ply and modified bitumen membranes are heavily marketed; they require less labor to install, carry manufacturer's warranties, and have replaced BUR in about half of the commercial roofing market. BUR systems are labor-intensive, while single ply and modified bitumen roofing systems require 100 percent effective lap joints. Materials for low slope roofing are discussed in subsequent chapters and summarized as follows:

a. Built-Up Roofing (BUR). BUR systems were improved by the introduction of glass fiber felts, and the development and standardization of good roofing technology. In military construction, the four-ply glass felt BUR is the predominant low slope roofing system. Built-up roofs are complex, but they can be relatively inexpensive and very reliable.

b. Single-Ply Membrane Roofing. Single-ply membranes are prefabricated sheets consisting of a single material, or several materials, designed to resist water penetration. Since only one ply must be placed, single-ply membranes require less labor to install than BUR, but single ply material is often more expensive than BUR materials.

c. Modified Bitumen Roofing. Modified bitumen consists of a bitumen, usually asphalt, with a polymer added to provide elastomeric properties and a fabric reinforcement to improve strength. Use of modified bitumen is expected to continue to encroach on the BUR and single ply market shares.

d. Fluid Applied Roofing. Fluid applied roofing materials include a variety of coatings and membranes which are available in solvent or latex dispersions. Colors may be aluminum, white, or black. These materials are used for temporary roofs, to extend the life of an existing roof and as a membrane over spray-applied polyurethane foam (PUF). Aluminized coatings are sometimes used on new roofs. Certain fluid-applied membranes may be used on protected membrane roofing.

e. Protected Membrane Roofing (PMR). PMR reverses the positions of membrane and insulation; that is, the insulation is placed on top of the membrane. The membrane may be any of the types described above, but the insulation is exposed to the elements and must have near zero water absorption. Extruded polystyrene is the only insulation recommended for this demanding service.

f. Polyurethane Foam. Sprayed PUF roofing consists of PUF insulation covered with an aggregate or a tough fluid-applied membrane. The membrane must resist abrasion, impact, water penetration and ultraviolet light.

2-2. Slope

Low slope usually means a slope of 4 inches or less. A minimum slope of 1/4-inch per foot is recommended to assure drainage. Most low slope roof membranes extend above any expected accumulation of water. Design life will be shortened when a roof must resist prolonged effects of standing water, even when the "head" pressure is limited to fractions of an inch. To prevent water accumulation, the structure must be designed to maintain the minimum slope at maximum deflection, even after prolonged stress, as from snow loads, traffic, or mechanical equipment operation.

a. Ponding. Ponding will add a load of 5 pounds per square foot per inch of water depth. Often roofs are designed for a live load as low as 25 pounds per square foot. A deflecting roof can allow a pond to accumulate and deepen; the increased weight can then quickly cause a catastrophic failure. Ponding should be avoided; ponds support plant life whose roots can penetrate both roof membrane and deck; water from a pond may increase damage by prolonging an otherwise brief leak, and most warranties are not valid for roofs showing evidence of ponding. If a pond cannot be avoided, refer to ASCE 7 for ponding loads and detailing and materials need close attention. Because of its self-healing properties, coal-tar pitch can perform well in a ponded roof. For containment or run-off of potable water, membranes should be limited to modified bitumen, butyl, EPDM, polyvinylchloride, bentonite and certain fluid-applied membranes.

b. Inadequate slope. New construction should always provide the required 1/4-inch minimum slope. Slopes less than 1/4-inch as on an existing roof, should be remedied by structurally converting the deck to low-slope. While initial costs may be lower when using tapered insulation, non-structural fill material and crickets, subsequent maintenance and replacement may not be cost-effective over the building's lifetime. Where the slope cannot be remedied, additional drains may be helpful.

c. Optimum slope. Roof slope should never be less than 1/4-inch. Increasing the slope above 1/4-inch will improve the ability of the roof to shed water, but costs will increase due to larger parapets, walls and supporting structures. For most low slope roofing membranes, the 1/4-inch slope is the best slope. Where the slope exceeds 1/2-inch many roofing membranes must be secured in place with nails or other mechanical fasteners. (Some fully adhered single-

plies do not require mechanical fastening.) Coal tar pitch should not be used on slopes which exceed 1/4-inch.

2-3. Drainage

Interior or exterior roof drains should be sized as needed for the drainage area, local rainfall rate, and roof slope. A minimum of two drains is required for each 10,000 square feet of roofing. More drains should be added when needed for irregular shaped roof or impedances. Potential sagging of the structure must be considered when drains are located near hard points such as columns and walls. Drains should be sized as specified in appendix D of the Uniform Plumbing Code or the SMACNA Architectural Sheet Metal Manual. In cold regions, low-slope roofs should slope 1/4-inch per foot to interior drains to avoid icicles and ice dams at eaves.

a. Interior Drains. Interior drains carry water through the inside of the building where it is less vulnerable to freezing. Interior drains can be used to limit the height of construction needed to provide the required slope. When using interior drainage, always provide overflow drains or scuppers in case a drain becomes blocked.

b. Exterior drains. Exterior drains include gutters, scuppers, leaders and downspouts located outside of the building. The outside edge of gutters should be lower than the inside edge.

c. Sumps. Shallow sumps may be beneficial around drains to limit ponding caused by the clamping ring, but abrupt, deep sumps are hard to waterproof and should be avoided. Drains should be located at low points, recessed below the membrane, and equipped with strainers.

2-4. Climate

In addition to climate considerations discussed in chapter 1, a low slope roof must be designed to withstand the expected maximum local rainfall and snow load.

2-5. Roof deck

The roof deck's structural resistance to loads from gravity, wind and seismic forces is beyond the scope of this manual. However, the deck must provide adequate slope, dimensional stability and resistance to deflection.

2-6. Roof selection

The type of roofing is limited by the type and slope of the roof deck and by local environmental conditions. Built-up roofing can be used for most low-slope decks between 1/4 and 2 inches per foot, and may be used for slopes up to 3 inches per foot. On slopes of 1/2-inch per foot or more, BUR must be backnailed in place. Asphalt shingle (or metal) roofing is used for most roofs steeper than 2 inches per foot. Single-ply membranes can be used on almost any roof slope. Built-up roofing and some single-ply

membranes are vulnerable to attack from petroleum or cooking oils and greases.

2-7. Roof mounted equipment

Equipment should not be placed on the roof, but it will be. The cost of a penthouse or equipment room is likely to be less than the cost of roof repairs and damage to the building interior resulting from placing equipment on the roof. Where equipment must be placed on a roof, construction details should be as shown in the NRCA Roofing and Waterproofing Manual and these precautions should be observed:

a. Group the equipment in a central location.

b. Do not install items directly on the roof membrane. The equipment should be mounted on full-flashed curbs at least 8 inches above the roof membrane.

c. Curbs should be flashed and covered with sheet metal caps unless the equipment base turns down and overlaps the base flashing by at least 3 inches.

d. Flashing must be compatible with the roof membrane.

e. Minimum height of equipment above the roof depends on the equipment size and is specified in the NRCA Roofing and Waterproofing Manual. When possible, equipment and utility runs which require curbs should be elevated at least 2 feet above the roof surface to provide clearance for roofing and flashing inspection, repair and replacement.

f. Distances between pieces of equipment and between equipment and roof edges should be equal to or greater than those shown in the NRCA Roofing and Waterproofing Manual to allow adequate room for installation of flashings.

g. Lightning protection conductors must not be run below the roof membrane.

h. Walkways, handrails and ladders should be provided for personnel servicing the equipment. Where the equipment requires vehicle access, the roof should be treated as a traffic deck.

2-8. Traffic surfaces

Roofs exposed to heavy pedestrian or vehicular traffic require a suitable traffic surface above the membrane. Traffic decks should be constructed in accordance with ASTM C 981 except as follows:

a. The minimum 1/4-inch slope requirement applies to structural deck under traffic surfaces.

b. The membrane may be BUR, sheet elastomeric roofing or fluid-applied elastomeric roofing. The membrane (except fluid-applied) is generally applied to protection board which is adhered to the 1/4-inch slope structural concrete deck. Aggregate must not be used over the membrane. The wearing course is applied to another protection board placed over the membrane. Boards must be waterproof. The wearing course may be concrete, tile, brick or paver blocks. For vehicular traffic, the minimum

wearing course is a 3-inch concrete slab reinforced with wire mesh. A drainage course of gravel or an insulation

layer may be placed over the top protection board and beneath the wearing surface.

CHAPTER 3

ROOF DECK

3-1. Functions

The roof deck carries roof loads, resists wind and seismic forces, provides a substrate for the other roof components, and should provide the slope of the roof. Loads are determined from ASCE 7, and should include construction and equipment loads. Structural resistance to loads is discussed in TM 5-809-1. An effective roofing system starts with a deck which provides a suitable base for the system, with adequate slope, dimensional stability, and resistance to deflection and to fire.

3-2. Design

Roof decks are constructed from one or more of the following materials: cement-wood fiber, lightweight insulating concrete, gypsum concrete, precast concrete, prestressed concrete, reinforced concrete, steel, wood plank, plywood and oriented strand boards. (See the NRCA Roofing and Waterproofing Manual for detailed descriptions of these deck materials.) Wood decks are seldom used in military or industrial construction. Factors which must be considered in the deck design are: drainage, dimensional stability, deflection, anchorage (for wind-uplift resistance), surface and joint conditions, expansion joints, and fire resistance.

3-3. Drainage

Slope for drainage should be provided by the structural deck, and will be 1/4 inch per foot or more in new construction. Saddles or crickets may be appropriate in valleys and other locations requiring additional drainage, but they should be avoided unless they can be carefully detailed and properly installed. Drains should be at low points regardless of maximum vertical deflection of the roof deck. Where provision of slope in the structural deck is impracticable, slope may be provided by tapered insulation or lightweight insulating concrete; either of which may be supplemented with stepped insulation. The choice between interior or exterior drains depends upon building size and configuration, the local climate and local code. Drains and gutters should be sized as recommended in the SMACNA Architectural and Sheet Metal Manual.

a. Interior Drains. Interior drains are favored in cold climate where subfreezing temperatures may create drain-blocking ice in exterior drains. Interior drain pipes may need to be insulated to prevent condensation. In all climates, use of interior drains will avoid the draining of water over a roof edge containing embedded metal. Such edges are weak links in all kinds of roofing systems.

b. Overflow Drains and Scuppers. Roofs with interior drains and perimeter parapets should be provided with overflow drains or scuppers for secondary drainage to limit ponding depth to a structurally safe depth in case the primary drains are clogged. Total scupper cross-sectional area should be a minimum 3 times the cross-sectional area of the primary vertical drains, and never any smaller than 4 x 8 inches to allow flashing application. Perimeter scupper drains should be designed by the same criteria as the primary drain system, using the “contracted-weir” formula:

EQUATION:

$$Q \text{ (cu. ft /min.)} = 200 (b - 0.2H) H^{1.5} \quad (\text{eq. 3-1})$$

where: b = scupper width (feet)
 H = hydraulic head (feet), assumed
 2-inch maximum depth

3-4. Dimensional stability

When the roof membrane is placed directly on the deck, rather than over intervening layers of insulation, any small movement of the deck can impose large loads on locally affected areas of the membrane. Dimensional stability of steel depends totally on thermal expansion and contraction. Plywood expands with increasing moisture content, which varies with the relative humidity. The dimensional stability of concrete depends on both temperature and moisture content.

3-5. Deflection

Each deck must be designed to limit deflection so that slope-to-drain is maintained at the maximum design load.

3-6. Anchorage

Recommendations of the manufacturer and FM or UL should be used for anchoring the roofing to the deck. For low-slope roofs, above-deck insulation board should be solid-mopped to base sheet or to the bottom layer of insulation which is mechanically fastened to the deck. For steep roofing, fastener sizes and patterns are specified in the NRCA Steep Roofing Manual, the ARMA Residential Asphalt Roofing Manual and ARMA Asphalt Roofing With Staples Manual. In addition to fasteners, lap cement is used at seams of roll roofing, and asphalt shingles have self-sealing strips. Clay, concrete and slate tile may need to be embedded in plastic cement. In high wind areas, tiles

may require special hurricane clips and additional head-lap.

3-7. Surface condition

The substrate construction of any bay or section of the building must be completed before roofing is placed. Roofing applied directly on lightweight insulating concrete should not be scheduled until the insulating concrete passes the air-dry density test. Roofing should not be applied directly on concrete until hot bitumen will not froth or bubble when applied to the concrete; and until the hot bitumen will stick tightly to the concrete. Vents and other items penetrating the roof should be secured in position and properly prepared for flashing. Nailers, curbs and other items attached to roof surface should be in place before roofing is begun.

3-8. Treatment of joints

Joints which will not move may be sealed and covered with a layer of felt or tape before membrane is placed. Most joints can move; these should be framed with curbs as described below. A less desirable alternative is to cover the joint with a preformed bellows, sloped to drain as shown (for EPDM) in figure K-1 of the NRCA Roofing and Waterproofing Manual. The bellows must provide sufficient freedom of movement to avoid stressing the flashing or membrane when the joint moves.

3-9. Expansion joints

Roofing systems need expansion joints where the building below contains an expansion joint, or should contain one as evidenced by movements there, or at the ends of deep long-span beams where motion can create the need for a flexible joint in the roofing. In addition to the joints placed over the structural joints, the roofing may need expansion joints to allow for thermal movement of the membrane and underlying insulation. Expansion joints should allow for movement in several directions and are best located on curbs with a minimum height of 8 inches. Roofs should be sloped so that expansion joints are at high points with drainage directed away from them; however, expansion joints will occur where they are needed for the structure,

and not necessarily at the roof designer's convenience. There is no reason to create an expansion joint in the membrane alone; membrane control joints should be avoided.

3-10. Area dividers

Roofs with H, L, E and U-shapes should be subdivided into rectangular areas that can be roofed one area at a time. The curbed features that subdivide such areas have no capability to move. They are valuable for adhered roofing systems since they eliminate re-entrant corners where stress concentrations may cause membrane splitting. Area dividers may not be needed for loose-laid ballasted single-ply membranes. For all other membranes, area dividers are appropriate where:

- a.* Deck material changes (e.g. from steel to concrete);
- b.* Span direction changes;
- c.* An existing building joins an addition;
- d.* Deck intersects with a non-bearing wall or wherever the deck can move relative to the abutting wall, curb or other building component.

3-11. Steel deck

Steel roof deck is light-weight, relatively inexpensive, and the most popular type of roof deck. Steel deck should be galvanized to provide corrosion resistance. The ribs or flutes must be bridged with a board substrate before a roofing membrane can be applied. Board edges parallel to flutes must be supported. The roofing system must be secured to steel deck by mechanical fasteners which penetrate the deck. Because of the fastener penetrations and gaps at edges and ends, steel decks cannot be considered to be vapor retarders.

3-12. Cast-in-place-deck

As working surfaces for application of insulation or roofing membrane, cast-in-place decks have the advantage over prefabricated decks (e.g. steel, precast concrete) in providing large deck areas without joints. Jointed decks should be designed to avoid elevation breaks or horizontal gaps in the substrate and to prevent bitumen dripping into the space below.

CHAPTER 4

INSULATION

4-1. Background

Thermal insulation can reduce both the amount of energy and the size of equipment needed for heating and cooling a building. The insulation improves the comfort of the building occupants and reduces potential for condensation.

4-2. Thermal resistance

The energy evaluation of a building will determine the required thermal resistance for the roof, through the application of design criteria and analysis of life cycle cost. Roof thermal resistance should meet or exceed agency criteria and requirements for Federal Buildings.

a. The NRCA Energy Manual contains a discussion of heat-flow calculations and additional information relative to economic insulation thickness for buildings. Calculations should be based on R-values for aged insulation because the R-value of some foam insulations decreases with time. Heat flow through fasteners and structural members should be included in the calculations.

b. High levels of thermal resistance are not always life-cycle cost effective, especially in buildings with high internal heat gains. Where these conditions exist, lower levels of thermal resistance may be justifiable.

c. Lower levels of thermal resistance may be justified on a life cycle cost basis where space heating is accomplished by heat recovery, economy cycle, or cooling tower, or where energy costs are minimal. Where energy is expensive, higher levels can be justified.

d. The required thermal resistance for each area of a building does not necessarily have to be the same throughout. Areas with long hours of operation and high internal heat gains will require less insulation than areas with little or no internal heat gain and/or short hours of operation.

4-3. Location

Roof insulation can be located either above or below the roof deck. In most buildings with low-slope roofs, above-deck insulation is preferred. Below-deck insulation is less expensive and provides better sound deadening, but can be vulnerable to moisture condensation in cold weather. When insulation is located below the deck, it may be necessary to provide a ventilated air space between the deck and the insulation. For this reason low slope roofs with only below-deck insulation should be avoided when the potential for condensation is high enough to require a vapor retarder. A “hybrid” system can resolve this by placing only a portion of the insulation below the deck.

Ventilated air space should not be allowed between a low slope deck and insulation below because such ventilation creates moisture problems. However, a cold steep-roof with permeable below-deck insulation should be vented to allow air to enter at the eaves and exit along the ridge. This type of vented steep-roof will reduce the risk of problems from condensation and ice dams in cold regions.

4-4. Fire resistance

A fire-rated steel deck must have a fire-resistant barrier between the steel deck and any flammable insulation or roofing membrane above the deck to retard ignition from a fire inside the building. The barrier may be 1 inch thick cellular glass, mineral fiberboard or perlite. The barrier may be the lower face of a composite panel, should be fireproof or not exceed a maximum flame-spread rating and should be secured by mechanical fasteners. Any adhesive applied to the steel deck must be fire-resistant. These requirements do not apply to insulation placed on concrete decks, or to insulation in roofing systems which are listed as Fire Acceptable by Underwriter's Laboratories or Factory Mutual.

4-5. Materials

Specific types and combinations of insulating materials are listed and discussed in the NRCA Roofing and Waterproofing Manual. Insulating materials are compared in terms of their resistance to the flow of heat or thermal resistance, reported as the R-value. In the following comparisons, R-value is defined as the resistance (R) to heat flow; measured as the difference in temperature between faces in degrees F per British Thermal Unit-hour per square foot for a 1 inch thickness. For example, $R = 5$, if, in 1 hour, 1 BTU would flow through 1 square foot of 1 inch thick insulation over a temperature difference of 5 degrees F. The specified R-values are approximate for each generic material and may vary for similar products from different manufacturers.

a. Soft blanket insulation cannot support a roofing membrane, but in some situations, it may be used beneath the structural deck, usually on top of the ceiling. (This can reduce the fire rating of the ceiling.) The ventilated space above a ceiling can be used to dissipate water vapor. Below-deck blanket insulation offers substantial cost savings as compared to above-deck insulating board but may require additional space (higher building costs). The ventilated space and deck above the blanket is vulnerable to effects of moisture condensation, freezing, and thermal expansion and contraction.

b. Insulation below or above a roofing membrane will be in the form of boards. Board insulation may be a single material or a composite of two or more preassembled layers of differing insulation materials.

(1) Composite insulation boards combine several functions, usually by sandwiching a foam (with high R-value) between facings which provide protection and a bonding surface. For example, a composite may have a facing that is compatible with the substrate adhesive, a layer of optimum R-value foam and a hard top layer to support the membrane. Composite board insulation can allow compliance with multiple criteria with a minimum thickness. Composite boards are not a substitute for a staggered double layer of insulation.

(2) Glass fiber board consists of glass fibers bonded with a resin binder and surfaced with asphalt and kraft paper or asphalt saturated glass fabric. Glass fiber board is inexpensive, has an R-value of about 4.2, and will conform to minor irregularities in the deck. Use of glass fiber board in roofing is limited because it has relatively low strength and high porosity which allows entry (and venting) of moisture.

(3) Cellular glass foam insulation board consists of glass cells which have been heat-fused into boards of uniform thickness or in tapered blocks. Cellular glass will resist compression and fire and has excellent moisture resistance. The cut edges of the board will absorb a little moisture and freeze-thaw cycles will damage such areas when moisture is present. Cellular glass is easily damaged, and relatively expensive. The R-value is about 2.6.

(4) Perlite consists of expanded volcanic glass and organic fiber mixed in a suitable binder and formed into boards of uniform thickness. Perlite is widely used as the first layer over steel deck and the last layer under hot-applied BUR membrane because of its high strength and high-temperature (and fire) resistance. The R-value for perlite is about 2.8.

(5) Polystyrene foam insulation has good resistance to moisture and heat flow. It can be laid in asphalt at temperatures not above 250 degrees F. and can be used as a substrate under BUR or modified bitumen provided that it is isolated from the hot asphalt by a layer of perlite, foam glass insulation or wood fiberboard. However, polystyrene is not a preferred insulation for use under BUR and modified bitumen; it has a much higher coefficient of thermal expansion than that of BUR and it will melt when exposed to high temperature asphalt or hot application of modified bitumen. Polystyrene, even with fire retardant treatment, should be treated as a flammable material. It is not compatible with coal tar. Organic solvents (including solvents in adhesives or paint) will dissolve polystyrene and collapse the foam cells.

(a) Molded polystyrene foam (MPS) or "bead-board" has lower moisture resistance, lower strength and lower thermal resistance than extruded polystyrene foam (XPS), but it is less expensive. In roofing, MPS is primarily used under loose-laid ballasted single-ply membranes. It can be used under BUR and modified bitumen membranes

if it is isolated as described above. Because of its limitations, applications of MPS must be considered in light of the manufacturer's recommendations and proven previous history in similar circumstances; as a result, MPS is difficult to specify. Some MPS products will absorb water and swell, precluding them from being used beneath any membrane. MPS should be selected and installed with caution; in addition to the manufacturer's recommendations and past experience with the material, a minimum density of 1.25 pcf should be required; and the designer and Contracting Officer should be satisfied as to the success of the product and skill of the installer in similar previous applications. MPS does not have sufficient durability and resistance to water absorption (or weather) for use above a protected membrane roof (PMR). The R-value of molded polystyrene is about 3.8.

(b) Extruded polystyrene foam has a smoother surface, tighter cell structure and usually higher cost than MPS. XPS is the only insulation that can survive above a protected membrane roof assembly. Water-based adhesives do not bond well to the smooth surfaces of XPS. R-value of XPS is about 5.0.

(6) Polyurethane and polyisocyanurate foams are very similar in both chemical and physical properties. Both materials have been used in insulation boards, but polyisocyanurate is now the most widely used, especially in composite boards. Glass fibers are sometimes incorporated into polyisocyanurate to improve fire resistance. Polyurethane foam (PUF) is used in spray-applied applications which are particularly useful for irregular contours such as Quonset huts. The PUF must be protected, usually with a fluid-applied membrane. R-value for either polyurethane or polyisocyanurate is about 6.2.

(7) Phenolic foam insulation is fire- and heat-resistant and has an R-value of about 8. Phenolic foam is no longer produced in this country, but may be found in existing roof systems (especially under coal tar membranes) which should be inspected carefully because, when moisture is present, phenolic foam has been known to contribute to the corrosion of adjacent steel components such as decks, fasteners and trusses.

(8) Wood fiber, particle, wafer or strand boards consist of one or more of these wood products, bound with a resin or asphalt, and formed into boards. These materials are widely used, especially in composite boards, and have an R-value of about 2.8.

c. Insulating concrete is poured-in-place and has many forms; it may be foamed concrete, or a mixture of concrete and an insulating material, typically hollow beads or foams made from perlite, vermiculite, glass or polystyrene. Insulating concrete has excellent compression strength and fire resistance. It will moderate the temperature extremes experienced by an adjacent membrane because the concrete mass stores and releases more heat than thinner, more efficient insulating materials. Insulating concrete is typically installed over perforated steel decks or formboard on low slope roof decks. The deck must be

allowed to dry downward. Insulating concrete may be used to encapsulate stepped or tapered polystyrene to provide roof drainage on an existing level roof deck. The polystyrene improves thermal resistance and decreases weight. A base sheet must be mechanically fastened to insulating concrete before installation of BUR or modified bitumen. Hot bitumen or adhesive should not be applied directly to insulating concrete. The use of insulating concrete is not recommended for new construction as it is easily damaged and expensive to replace when re-roofing is required. The R-values range from 13 to 2.5, depending on the selection and proportion of the insulating constituent.

d. Physical property data is usually available from the insulation manufacturer and often consist of laboratory test reports. Such data should be appropriate for the conditions under which the roof will perform. Generic physical property data is published in the NRCA Roofing and Waterproofing Manual. Where data reported by insulation manufacturers differs from that shown in handbooks, appropriate justification and explanation should be obtained.

4-6. Application criteria

a. When it is cost-effective, insulation should be applied in two or more layers with joints staggered to avoid direct paths for heat flow. Besides blocking heat flow at joints, the double layer allows firm attachment of the first layer to the deck while the top layer acts as a cushion and isolates the membrane from movement of the deck.

b. The types of insulation to be used must be appropriate for the roof assembly; that is, they must be compatible with adjacent materials and provide specific characteristics as required by the application. Open cell structures of glass or isocyanurate should be isolated from the membrane. Polystyrene should not be used where it may be exposed to hot bitumen or any coal tar or organic solvent, fuel or oil. Glass fiber insulation should be avoided where moisture may penetrate the insulation system or where its low compression strength will allow the membrane to be damaged by traffic.

c. Most insulation should not be loose-laid; it should be secured in place with bitumen, adhesive or fasteners. An exception is the protected-membrane insulation which is held in place by ballast or pavers.

d. To avoid blistering of the membrane, polyisocyanurate, phenolic, polystyrene and polyurethane foam insulations must be isolated from BUR or modified bitumen membranes by separate or composite layer of cellular glass, mineral fiberboard, or perlite board.

e. Additional data concerning specific compatibilities of each type of insulation with each type of roof deck and roof membrane are available from insulation manufacturers and the NRCA Roofing and Waterproofing Manual.

4-7. Storage

Insulation must be kept dry, both when stored on the job site and when installed on the roof. Stored insulation should have a waterproof cover; should be elevated to avoid contact with surface water or ground moisture; and must be secured from blowing away. Wet insulation should be marked and rejected. Newly installed insulation must be covered with completed roofing membrane at the completion of each day's work.

4-8. Properties

The ideal insulation would be compatible with other roofing system components, resistant to impact, fire, moisture, and temperature variations; and it would be high in thermal resistance and low in cost. Since all of these ideal properties do not exist in a single material, combinations of materials are generally used. Specific properties are as follows.

a. Compressive Strength. The insulation immediately under the membrane should be a compression-resistant material such as perlite or fiberboard (or insulating concrete), especially where roof traffic (including construction traffic) will be heavy, or exposure to hail is expected. Cellular glass also has good compression resistance, but the cell faces should be isolated from the membrane with, for example, a layer of perlite.

b. Moisture Absorption. Extruded polystyrene is the only insulation that can survive unprotected for years in a wet environment subject to freezing and thawing. For that reason, it is the only insulation that should be used above the membrane in a protected membrane roofing system. A major design goal of all other roofing systems is to keep the insulation dry with a good waterproofing membrane and, if necessary, a vapor retarder. Thus, for most roofs, it is not necessary to use a moisture resistant insulation such as extruded polystyrene. However, permeable insulations such as fibrous glass should be avoided in buildings with a high risk of condensation, i.e., those with hot humid interiors in cold places, and cool buildings in hot humid places. In a high-rise building with either of these conditions, any low-permeability insulation should be fully adhered to its substrate to minimize air leakage and vapor diffusion. The vapor traps so created can be accepted.

c. Dimensional Stability. Changes in the dimensions of insulation may damage the membrane. Cellulosic fiber insulation will swell with moisture absorption and shrink when drying. A four-foot long cellulosic board can contract 1/4 inch, thus opening a gap. A 100 degree temperature drop can shrink a 4 foot polystyrene or polyurethane board nearly 3/16th of an inch. Large thermal movements are usually restricted by placing a more stable material directly below the roof membrane.

d. Temperature. During cold weather, clear sky radiation can result in roof temperatures lower than design temperatures. Intense solar radiation on a black or dark-colored roof can generate surface temperatures in excess of 150 degrees F. Temperature ranges of more than 100 degrees F can be experienced in a single day.

e. Chemical Compatibility. The insulation must be compatible with other components of the roof assembly. As an example, polystyrene is not compatible with coal tar and most oils, greases and solvents.

f. Physical Compatibility. When using unfaced plastic foam insulation under built-up or modified bitumen roofing, an additional top layer of wood fiber, fiber glass, or perlite insulation should be specified to guard against membrane blistering. To prevent melting, as in the case of polystyrene, the top layer is mopped, allowed to cool briefly, and then flopped onto the polystyrene below.

g. Thickness. With the high thermal resistance (i.e., low U-value) commonly used for roof insulation, the thickness of insulation can be a substantial consideration in roof design. Drawings should allow adequate space for insulation and should show required thermal resistance (R-value) of insulation.

h. Layering. When board type insulation is used, it is generally necessary and preferred to have multiple layers. Joints should be staggered between layers. Proper type and length fasteners should be used to avoid lateral movement of the roof insulation. Layering will reduce heat transfer through fasteners when the bottom layer is mechanically fastened and the top layer is adhered to it. Compliant fibrous glass insulation can be placed in boards

as large as 4 x 8 feet, but rigid insulation should generally be placed in smaller pieces sized to fit subsurface irregularities.

i. Contractor Options. Where the overall roof thermal resistance is specified and the contractor is given the option to install more than one type of insulation material, the limitations on thickness and compatibility should be clearly set forth. The design should account for variations in insulation thickness which are likely to occur, making provision for parapets, flashing, curbs, wood blocking, and treatment of slope to roof drains. Contractor options will be restricted when FM or UL approval is required.

j. Anchorage. The roof insulation must be secured to the roof deck, by means such as adhesives and/or corrosive resistant mechanical fasteners, which are compatible with the materials used. For steel decks, the bottom layer of insulation must be attached with penetrating fasteners. Roofing should be mechanically fastened in all cases where the slope exceeds 1/2 inch per foot.

4-9. Tapered insulation

Manufacturers provide various tapered insulation configurations using several different materials. Where tapered insulation is to be used, dimensions must be detailed to ensure the proper slope and positive drainage. Tapered insulation is sometimes a necessity in new construction but will add to the life cycle cost because wet or damaged insulation may have to be replaced when the roof is repaired or replaced. The varying thickness must be considered in the design of the attachment system.

CHAPTER 5

BUILT-UP ROOFING

5-1. General

Built-up roofing (BUR) is used more than any other type of roofing for all slopes of 2 inches per foot or less, and can be used on slopes as steep as 6 inches. The four-ply glass felt roof is the most often used roofing in military construction.

a. Advantages. BUR systems are usually built from relatively inexpensive materials; they are durable when properly applied; and skilled contractors are available in most parts of the country. Vapor retarders can be fabricated from the same felt and bitumen used in the roof membrane. Most BUR manufacturers will provide a “complete system” with a 20 year warranty provided that the manufacturer can control the materials and workmanship.

b. Disadvantages. Installation of BUR is skilled-labor intensive and requires hot bitumen with its heating kettle and careful control of application temperature. BUR is generally not suitable for application in temperatures below 40 degrees F. When specifications permit a BUR system to be assembled from components from different suppliers, a single manufacturer’s warranty may not be available for the completed roof system. BUR membranes are vulnerable to substrate movement; they have less elongation capability than many single-ply or modified bitumen membranes, and they are vulnerable to attack by solvents, oils and greases. BUR membrane must be protected from weather and excessive heat by a surface treatment. Unprotected BUR is vulnerable to damage from ultraviolet light, heat, hail, and erosion.

5-2. Description

Glass fiber BUR consists of layers of glass felts held in place and laminated together with a bitumen, and usually protected from the elements by a bitumen flood coat and some form of surfacing. A properly installed four-ply glass felt BUR roof, with yearly inspections and adequate maintenance, can be expected to last for 20 years or more. Like any roofing system, the full life expectancy can only be achieved with proper design, quality workmanship and a good inspection and maintenance program.

a. For details on flashings, anchorage, felt laps, felt backnailing, metal work, and application of built-up membranes to various substrates, refer to the NRCA Roofing and Waterproofing Manual, and SMACNA Architectural Sheet Metal Manual.

b. Pitch pans (or pockets) should be avoided. When required in re-roofing, pitch pans should be filled with pourable sealer with top sloped to drain. Bitumen should not be used in pitch pans. Several detail sheets in the

NRCA Roofing and Waterproofing Manual provide methods for avoiding pitch pans.

5-3. Bitumens

The bitumen resists water penetration, bonds the felts to the substrate and to each other, holds the surface aggregate in place, and sometimes provides the base for a protective coating or surfacing.

a. Blown (oxidized) asphalt is the most commonly used bitumen in built-up roofing systems. Asphalt is graded based on softening point temperature from Type I to IV. Type I is used on very low slopes; it is the softest and most likely to self-heal. Type IV is called “steep asphalt” because it may be used on slopes as steep as 3 inches per foot. Type IV asphalt has the most resistance to cold-flow, but it is hard and brittle and not self-healing.

b. Coal-tar pitch may be used in roofs which do not exceed 1/4-inch slope. Since a 1/4-inch minimum slope is mandated for new construction, it is normally the only slope permitted for coal tar pitch. Coal-tar pitch will flow at lower temperatures than asphalt; this cold-flow property allows it to “self-heal” more readily than even the softest (Type I) asphalt. Coal tar pitch is preferable to asphalt for roofs where ponding of water cannot be avoided. Special configurations are available for ponds or reservoirs which are not considered herein as “roofing.” (Ponding is discussed in chapter 2).

5-4. Felts

Felts stabilize and reinforce the membrane, prevent movement of the bitumen, and distribute loads. Felts separate the inter-ply moppings to provide multiple lines of waterproofing defense. Glass felts should be used for BUR roofing.

a. Organic and asbestos felts are vulnerable to deterioration from exposure to moisture, and have generally been replaced by glass felts. Organic felts can be crushed or molded into place; they are used for temporary membranes, edge envelopes and bitumen stops. Some commercial coal-tar systems still use organic felts. Asbestos is not permitted in Army construction.

b. Glass felts are durable, strong and moisture-resistant, but must be laid flat or in very gentle curves because of their “memory;” that is, they tend to return to their initial flatness and may spring or gradually pull back out of the bitumen when bent into complex shapes.

c. Polyester felts have good elongation properties and they can be formed more easily than glass felts since they usually have little or no “memory.” Polyester felts do not have wide acceptance because there is no procurement

standard, they are expensive and flammable, and they can be damaged by excessive bitumen temperatures. (Polyester felt or fabric is used in some proprietary modified bitumen membranes).

5-5. Surfacing

Surfacings protect bitumens from being degraded by exposure to traffic or other mechanical abuse and weather; especially sunlight, heat, hail and erosion. Three types of surfacing for built-up membranes are coatings, mineral aggregate, and mineral-surfaced cap sheet. Light or aluminum-color coatings are often used in moderate and hot climates to reflect heat from the sun and prevent ultraviolet damage to the membrane. Acrylic coatings can be used in warm regions on roofs with good slope-to-drain; but they do not perform well when exposed to freeze-thaw cycles. Aggregate is the most generally used and the most durable of the surfacings. A glaze coat of asphalt is usually not an adequate surface as bare asphalt is degraded by UV exposure. Bare asphalt and most organic coatings are susceptible to fire and physical damage. In moderate or hot climates, aggregate or mineral-surface should be light colored and opaque to ultraviolet light.

5-6. Flashing

Flashings seal the joints where the membrane is interrupted or terminated. Base flashings are essentially a continuation of the membrane and form the edges of an (ideally) watertight tray. Counter-flashings shield or seal the exposed joints of base flashings. The following materials are recommended:

a. Base flashings may be modified bitumen or three-ply of glass fabric laid in and covered with roofing cement or hot asphalt and overlaid with a mineral-surfaced roll roofing. Glass fabric flashings must be carefully designed and crafted to avoid bends where the fabric can move back to its original flat shape. This is not a problem with modified bitumen flashing. Base flashings should be used at parapets, walls, expansion joints, and curbs which frame access hatches, vents, or equipment openings.

b. Modified bitumen flashings are versatile and effective and they are compatible with BUR. Because of the large number of products and lack of standards, modified bitumen flashings are often procured "as recommended by the manufacturer," in the form of one-ply sheets, 160 to 200 mils thick, normally reinforced with polyester or glass fibers. Single-ply modified bitumen is usually the prime choice for flashing built-up roof membranes.

c. Metal base flashings should be restricted to applications where there are no practicable alternatives such as vent-pipe seals, gravel-stop flanges, and drain flashings.

d. Counter-flashings (sometimes called "cap flashings") are usually made of metal: aluminum, galvanized steel, stainless steel, or copper sheets. They are designed to shield exposed base flashing terminations and to shed water from surfaces which are vertical or inclined to the

roof. They may be tied into reglets or through-wall flashings. Compatible fasteners must be used to anchor metal counter-flashing to prevent electrochemical corrosion.

5-7. Flashing design

Good flashing design requires the following:

- a.* Elimination of as many penetrations as practicable;
- b.* Separation of roof penetrations by at least 18 inches;
- c.* Consolidation of as many openings as possible into a smaller number of larger openings;
- d.* Location of flashed joints above the highest water level on the roof, with drainage away from flashed joints;
- e.* Allowance for differential movement between base and counter-flashing;
- f.* Firm connection of flashings to solid supports;
- g.* Contouring of bituminous base flashings with cants to avoid sharp bends.

5-8. Differential movement

Flashing details must provide for movement among the different parts of the building where such relative movement is possible. For example, the deflection of along-span open-web steel joist alongside a parapet wall may exceed 1/2 inch. The intersecting element may be a wall, column, pipe, curb or other building component. If the flashing is attached directly from the deck to the intersecting element, it will be torn and the roof will leak. Base flashings should be anchored to the structural roof deck, but they may have to be free of the intersecting element and then be protected by an umbrella type counter-flashing anchored to the element. Where the wall and deck are monolithic, there should be no differential movement and the base flashing can be fixed to both wall and deck.

5-9. Contours

At angles between the roof and walls or other vertical surfaces, built-up membrane or flashing material should be installed over cants to prevent bending the material more than 45 degrees. Cants should be required for most applications. Wood cants, pressure-treated with water-base preservatives, may be preferable to fiberboard cants, especially where they brace the right-angle joint between vertical and horizontal nailers at equipment or wall nailers or wall curbs. Cants under torch-applied modified-bitumen flashing should be fire-resistant (for example, glass foam or concrete).

5-10. Compatibility

Manufacturers' data should be consulted for compatibilities of specific products. Bitumens in BUR can damage materials such as polyvinyl chloride (PVC). Polystyrene, PVC and EPDM are vulnerable to damage from coal tar bitumens and solvents (including solvents in some

adhesives). These materials should be isolated from the BUR.

5-11. Quality control

Proper selection and installation of materials are critical to the performance of built-up roofing. Materials include the

selection of the proper asphalt for the slope; complete flashing details in the drawings, and control of application techniques. The proposed roof system and materials must be compatible with roof deck (including slope), vapor retarder, insulation, and geographic location. The design must meet applicable PM or UL requirements.

CHAPTER 6

SINGLE-PLY ROOFING

6-1. General

Single-ply roofing (SPR) comprises about one-third of all low slope roofing. Over 100 manufacturers produce several hundred types of SPR membranes which are sometimes more expensive to buy and usually easier to install than BUR. SPR is frequently used for re-roofing and for areas where chemical resistance is needed.

a. SPR may be unreinforced, laminated, or reinforced with woven or non-woven fabric or fiber. Some forms of SPR are available only by their commercial designations and cannot be procured generically.

b. Chemically, sheet-applied membranes are classified as cured or uncured elastomers (synthetic rubber); plasticized thermoplastic polymers; and modified bitumens. Modified bitumens are discussed in chapter 7.

6-2. Elastomeric sheets

The most common elastomeric sheet is known as ethylene propylene diene monomer (EPDM). Technically, the “monomer” is a “terpolymer” since it consists of three molecules; and the material, as used, is a polymer, composed of long chains of the terpolymers. This manual follows the roofing industry practice of referring to EPDM as ethylene propylene diene “monomer.”

a. A few manufacturers provide EPDM polymers to a larger number of sheet fabricators who add fillers, chiefly carbon black and oils, and sometimes surface the product with mineral particles. The EPDM roofing materials are marketed under a variety of trade names, but they generally behave similarly; they have good resistance to ozone and weather, and they maintain high tensile strength and elongation for many years. EPDM has good puncture resistance and can be repaired, even after aging on the roof. It can be damaged by exposure to oil, grease or fuel from sources such as kitchen or engine exhausts, and mechanical equipment. The problem can be avoided by protecting the EPDM with an oil-resistant overlay or by replacing the EPDM in the area of the potential exposure with an oil-resistant membrane.

b. Field lap seams are a critical component in elastomeric systems. EPDM is a thermosetting polymer which requires use of contact adhesives to bond the material to itself or to a substrate. These contact adhesives generally require thorough cleaning of the surfaces with solvent-soaked rags, a waiting period for the contact adhesive to attain proper consistency, and thorough pressure-sealing of the lap. Lap joints are usually best when the adhesive is about 8 mils thick. Thinner layers tend to leave gaps in the bonding. Pre-formed tape is sometimes used as a carrier for the adhesive. Surface oxides develop during prolonged

exposure to the elements and must be removed before the membrane can be repaired.

c. Lap seams are vulnerable to moisture intrusion, especially when exposed to freeze-thaw cycling. Over a long period of time, the intruding water impairs the performance of contact adhesives and tapes. Some materials, such as butyl adhesive, have improved resistance to such exposures, but defective field-prepared lap seams are always likely to fail. Some systems apply a sealant to the lap edges to protect the seam while it cures.

6-3. Plasticized thermoplastic sheets

Polyvinyl chloride (PVC) is the primary roofing material classed as a plasticized thermoplastic sheet. It can be molded or bonded by heat. PVC requires a plasticizer to provide flexibility since PVC by itself is brittle. Prolonged exposure to weathering, especially sunlight and heat, will cause plasticizer to migrate out of the compound; this may cause some unreinforced membranes to shrink and become brittle. A reinforcing material provides dimensional stability by preventing or minimizing the shrinkage and embrittlement resulting from plasticizer migration. Unreinforced PVC roofing membranes are not permitted in Army construction.

a. PVC sheet offers field-seaming of watertight lap joints by solvent- or heat-welding the lap seams. Properly made, such a seam is a true fusion of base and jointing material, and makes a watertight joint. In heat welding, the two layers flow together and then cool quickly into fused single material. The solvent, or “cold-weld” is the more difficult process for a little of the PVC is dissolved from each surface and the surfaces must be held together until the solvent dries.

b. Some PVC sheet membranes become embrittled and shrink from loss of plasticizer. Unreinforced PVC membrane has a high coefficient of thermal contraction-expansion. Only reinforced PVC should be used for roofing membrane.

c. PVC is not compatible with bitumens, oil or grease.

6-4. Uncured elastomers

Uncured elastomers continue to “cure,” or polymerize as they age; this is marked by increasing tensile strength and decreasing elongation and elasticity. The most common single-ply membranes in this category are CPE (chlorinated polyethylene), CSPE (chlorosulfonated polyethylene, known commercially as Hypalon), and PIB (polyisobutylene). Their lap seams can be bonded by heat, solvent, or adhesive. Aging is critical to these materials; when shelf life expires, the membrane may become difficult

to bond. After aging in a roof system, it may be difficult to patch.

6-5. Perimeter anchorage

Single-ply membrane systems are anchored at their perimeters and at openings. Loose-laid systems receive maximum membrane tensile forces at perimeters and other terminations. The main purpose of perimeter anchorage is to increase wind resistance. In addition, the perimeter anchorage is expected to:

- a. Prevent stressing flashings, which could either split or pull loose from their backings and become vulnerable to puncture.
- b. Restrain contraction in materials subject to long-term shrinkage.
- c. Reduce membrane wrinkling which may obstruct drainage.

6-6. Field anchorage

Single-ply membranes can be loose-laid and ballasted, adhered, or mechanically fastened to the deck. Manufacturers customize membranes for a specific type of anchorage.

6-7. Design recommendations

In addition to design recommendations for decks and insulation, design for SPR roofs on new facilities should include the following:

- a. A minimum 1/4 inch per foot slope is required for all roofs and a 2 inch per foot slope is the maximum permitted for loose-laid, ballasted systems.
- b. The proposed systems must be evaluated for material properties, limitations, advantages and disadvantages, and past performance (10-years in the geographic location of the site).
- c. Wind and fire resistance requirements should be determined.
- d. Substrates must be suitable. Sheet membranes may be applied to structural concrete (cast-in-place and precast), lightweight insulating concrete with low moisture content, plywood, and rigid insulation board. Generally, a slip sheet or insulation board is placed between the deck and the membrane.
- e. For cast-in-place concrete decks, each concrete curing agent must be compatible with the membrane. Some curing agents can cause poor adhesion or even premature deterioration of the membrane.
- f. Plywood should be 5/8 inch minimum thickness, smooth-surfaced exterior grade, with edges supported to limit differential deflection of adjacent panels to 1/8 inch at panel edges and 1/16 inch at ends.
- g. Lightweight insulation concrete fills, gypsum deck, and rigid insulation boards are suitable substrates for mechanically fastened or loose-laid sheet membranes.

- h. The membrane must be repairable in case of future damage.

6-8. Information required for design

a. *Geographical Location.* Climatic conditions at project site.

b. *Roof Deck*

(1) *Structural capacity:* For loose-laid, ballasted systems, design for additional 10 to 25 pounds per square foot dead-load capacity for ballast;

(2) *Deck type:* Anchorage technique, vapor retarder, venting, wind-uplift, and fire requirements;

(3) *Slope:* Component anchorage, wood nailers, and insulation stops.

c. *Special Occupancy Factors.*

(1) *Humidity:* vapor retarder and venting requirements must be determined.

(2) If there is waste spillage or exhaust onto roof surface, determine the nature of waste material. Periodic roof wash-down may be required; limited areas may need special membrane, or special membrane maintenance.

(3) Chance for occupancy change (e.g. from low to high humidity).

d. *Roof Insulation.* The roof insulation should be secured to the deck. Loose laid single ply membrane should not be placed over loose-laid insulation. The insulation is likely to shift and leave gaps or heave at joints.

e. *Special Requirements.* Requirements must be determined for flashing of walls, parapets, curbs, platforms, equipment platforms, penthouses, roof-traffic areas, conduit or pipe supports, etc.

f. *Temporary Roof.* A temporary roof may be required due to location, construction schedule, or climate. Since the temporary roofing must be removed before permanent roof application, the added cost must be warranted.

g. *Roof Deck Treatment/Preparation.* Insulation can cover small deck imperfections; but when the membrane is applied directly to the deck, seams and joints must be smooth and continuous.

h. *Vapor Retarder.*

(1) Specification should include the type of material, method of securement, sealing at laps, projections and drains, envelope at perimeter edges, etc.

(2) Adhesives, films and insulations must be compatible.

6-9. Design requirements

When a manufacturer's warranty, is wanted, these details must be technically appropriate and acceptable to the manufacturer. Details include:

a. Type of underlayment or slip sheet, if required, lap seaming techniques, placement of underlay at metal work, barrier properties for coal tar fumes, and bitumen contact.

b. Anchorage techniques: Nailers should be specified, especially at perimeters and curbed penetrations.

Mechanical fasteners must be proper type and appropriate for deck. It may be necessary to specify length, installation method, size of washer, disk or nailer strip. Special tools should be indicated if necessary. For adhered systems, substrate must be appropriate and in suitable condition, cleaned, or primed. Type, quantity, application methods, dry time and test should be specified for adhesives.

c. Membrane: End and side laps, terminations, sealing methods, temperature or other weather limits for solvent or heat welding should be specified.

d. Surfacing: Aggregate for ballasted roofs should be specified by quantity, screen gradation, or designated size. Indicate whether or not aggregate can be directly applied to membrane or if a protection layer is needed. For color coating specify surface preparation, temperature limits, upper and lower limits on quantity per coat, method of application, curing requirements, etc.

e. Protection: Adjacent areas and utility lines should be protected from roofing traffic or spills.

6-10. Flashings and cants

Flashings, cants, and drainage fittings must be clearly detailed and specified. Specific detail plates may be cited, or the flashings and cants may be detailed on the drawings.

6-11. Sheet metal work

In military construction, sheet metal work is treated as separate from, but coordinated with the roofing specification. For the roofing to be effective, the sheet metal work must be accurately specified, detailed and coordinated with the roofing work.

6-12. Applicable details

Flashing and roof system details are available in the NRCA Roofing and Waterproofing Manual. Sheet metal details may be found in the SMACNA Architectural Sheet Metal Manual and manufacturers' information.

CHAPTER 7

MODIFIED BITUMEN ROOFING

7-1. General

Modified bitumen is treated herein as a separate class of roofing because it occupies a large share of the roofing market and includes a variety of products and application methods. All types of bitumens maybe “modified” but, for roofing products, modified bitumen membranes are generally factory made by mixing a polymer (the “modifier”) into an asphalt and then reinforcing the resulting compound with fabric. The selection and quantity of the asphalt, modifier and fabric reinforcement determine the properties of the final product.

a. Specifications. Modified bitumen roofing has been specified based on product description, and qualified by demonstrated performance by the manufacturer, installer and the roofing system in similar applications and climate over a period of years. Adoption of an industry procurement standard has been complicated by the large number and variety of modified bitumen roofing products which are marketed. Canadian specifications are cited in the NRCA Roofing and Waterproofing Manual.

b. Advantages. Modified bitumen is easy to apply and may have better tolerance to temperature extremes and weathering than BUR. It may be better able to accommodate small movements of the substrate and is probably the best material available for flashings, both for modified bitumen roofs and for BUR. Modified bitumens are compatible with built-up roofing materials, lighter in weight than BUR, and thicker than most other single-ply roofing membranes. It is economical, durable, and some can be applied in cold weather. It remains easy to repair after prolonged weather exposure. Modified bitumen is less expensive than some single-ply roofing membranes. In some cases, the ease of installing modified bitumen can offset the lower materials costs of BUR.

c. Disadvantages. Because there are hundreds of modified bitumen roofing products, the industry has not been able to establish a single adequate procurement specification, and experience with existing standards is limited. Lap-joint failures have been reported due to poor workmanship and due to variations in the properties of the material. Since procurement by generic description is difficult, the product is sometimes specified by requiring demonstrated performance in similar applications. Deterioration may be expected when it is exposed to oils, greases and fuels, but the membrane may be protected with an oil-resistant coating or overlay.

d. Composition. Polymers most-commonly used in the modified bitumen membranes are atactic polypropylene (APP) and styrene-butadiene-styrene (SBS). Reinforcement may be in the form of a supporting fabric, or may be mixed or embedded within, or laminated to the modified

bitumen. Reinforcement may consist of woven or non-woven fibers or films, sometimes in various combinations, and composed of plastic film or mat, glass or polymer fibers or fabrics.

e. APP Application. APP modified bitumen membrane must be torch or heat-applied as it does not bond well to bitumens or adhesives. Because of the problems with adhesion, several manufacturers have stopped producing APP membranes and they are not recommended for Army construction. APP modified bitumens generally have better heat resistance than SBS modified bitumen, and some have been used successfully in cold regions.

f. SBS Application. SBS modified bitumen membrane may be installed with torch or heat application, or by embedding it in hot bitumen, or cold adhesive. SBS modified bitumen membranes have better low temperature flexibility and elongation (better cold-weather performance) than the APP types.

7-2. Design considerations

a. Analysis. The design must consider type of underlayment, anchorage technique, manufacturer’s specification criteria, UL fire classifications and code criteria for underlayment and membrane material. APP modified bitumens may exude oils, especially during exposure to heat and sunlight. For this reason, some manufacturers recommend immediate coating or surfacing of APP modified bitumens, rather than waiting the customary 30 to 90 days. No such concern has been raised regarding SBS modified bitumen membranes.

b. Materials. Design must specify type of adhesive bitumen; grade of bitumen; roof slopes; and heating or handling limitations, and consider manufacturer’s criteria.

c. Application Criteria. Unless specified by the manufacturer, the anchorage technique, brooming, extra reinforcement, protection of partially completed surfaces, and torching or trowelling of laps, should all be specified. “Torching” should be prohibited on buildings with combustible substrate components. Where torching is allowed, the substrates must be flame resistant; the presence of a single flammable cant strip can result in disaster.

d. Surfacing. Appropriate surfacing, if required must be specified as to size, color and quantities of surfacing aggregate. If surface coatings are required, the specification must detail preparation of surfaces, quantities, approved method of application, number of coats, protection of adjacent surfaces, and if loose granules are to be sprinkled into exposed bitumen at seams or laps.

e. Protection. Materials must be properly stored at the site. Completed sections and building premises must be protected from spills.

7-3. Quality control

a. Modified bitumens are vulnerable to variations in type and source of asphalt and to effectiveness of the blending of the polymer. Microscopic examination under ultraviolet light can be used to verify thorough dispersion of the polymer into the asphalt. In a good mix, the polymer fluoresces as a uniform yellow around tiny spots of black asphalt. In a poor mix, the asphalt will appear as large

spots or clumps. This type of examination is usually limited to factory control, but some manufacturers will provide results of such examinations.

b. Finally, the project specification and manufacturer's quality control precautions must be enforced during procurement, storage and application of the materials, including deck, vapor retarder (if any), insulation, membrane, flashings and surface finish or aggregate.

CHAPTER 8

PROTECTED MEMBRANE ROOFING

8-1. General

Protected membrane roofing (PMR), also known as “up-side-down roofing” reverses the positions of membrane and insulation in the conventional membrane roofing system. Instead of its normal exposed position on top of the insulation, a protected membrane is sandwiched between the insulation above and the deck below. A PMR system, from bottom up, may include the following components:

- a. Deck.
- b. Suitable underlayment leveling board (steel decks only).
- c. Insulation.
- d. Membrane.
- e. Protection board.
- f. Percolation layer.
- g. Insulation (above the membrane should be extruded polystyrene, and may contain drainage channels in the bottom).
- h. Filter fabric.
- i. Ballast (aggregate or pavers).

8-2. Design criteria

a. *Structural Capacity.* The structure’s load-carrying, capacity must be adequate to carry the ballast.

b. *Slope.* The membrane must slope a minimum 1/4 inch per foot. Slope should be built into the structure.

c. *Climate.*

(1) PMR’s are well-suited to hot or cold climates as the insulation protects the membrane from temperature extremes and reduces potential for condensation problems. In cold climates the membrane doubles as a vapor retarder.

(2) A thin layer of less expensive insulation below the membrane can also reduce heat losses and condensation potential from convective and evaporative cooling following a rain. If the dew point is below the membrane, a vapor retarder may be needed. For additional energy savings, another type of insulation under the membrane may be more cost effective than extruded polystyrene above the membrane.

(3) For cooled buildings in humid tropical climates, the best location for the membrane is above most of the insulation where the membrane also serves as a vapor retarder. PMR systems are excellent for areas with high ultraviolet exposure.

8-3. Materials

The membrane may be built-up roofing, modified bitumen, single-ply sheets, or fluid-applied. Fully adhered membranes have been more successful than loose-laid or mechanically attached systems.

8-4. Drainage

a. The key to a properly functioning PMR is fast rain-water runoff, assured by a sloped, fully-adhered membrane, percolation course, well-drained insulation, and suitable ballast.

b. Roof drains should be located where they will not freeze. The first few feet of pipes from drains may require thermal protection in cold regions.

c. Overflow scuppers or drains should be provided in case primary drains become blocked.

8-5. Flashings

Flashings for a PMR are essentially the same as for conventional roofs. At eaves the insulation may be bevelled to protect the flashings. Flashings should be carried a minimum 6 inch height above the top of the ballast.

8-6. Other considerations

a. A modified bitumen or a four-ply fiberglass built-up system set in hot bitumen are the most common membranes for a PMR. For BUR, the flood coat should be applied in two separate moppings. Sometimes a 4 mil (minimum) polyethylene sheet is applied over the BUR to prevent bonding of the insulation to the BUR.

b. Expansion joints and area dividers should be handled as described in chapters 2 and 3. Pre-formed joint-formers and hidden expansion joints should not be used.

c. A water test of the membrane and flashing system is recommended before the insulation is installed.

8-7. Applicable details

Details are available in the NRCA Roofing and Waterproofing Manual, the SMACNA Sheet Metal Manual, agency guide specifications, and design information and specifications of extruded polystyrene insulation manufacturers.

CHAPTER 9

FLUID-APPLIED ROOFING

9-1. Membranes and coatings

Fluid-applied membranes and coatings are formed by solidification of a fluid: either by drying of a solid material which has been dispersed in a liquid, or by polymerization (curing) of a material supplied in an uncured (usually two-component) state. A coating protects the surface which is usually a membrane; but the coating does not provide the primary waterproofing barrier. A membrane provides the primary waterproofing barrier. Both coatings and membranes can seal cracks, block ultra-violet light, and reflect or absorb heat from the sun. They are often used to extend the life of bare asphalt or roll-roofing.

9-2. Dispersions

Most fluid-applied materials consist of a solid which is dispersed or dissolved in a liquid. After application, the liquid evaporates and leaves the solid as a permanent coating. Solvent dispersions include neoprene, chloro-sulfonated polyethylene (Hypalon), butyl rubber and bitumen. A bitumen dispersed in solvent is sometimes called a “cut-back” and may be used as a primer. Most water-based (latex) dispersions are acrylic coatings.

9-3. Two-component systems

Two-component coatings and membranes solidify by action of a catalyst or by chemical reaction between the two components; they have a high solids content and contain little or no solvent. Polymers in two-component systems are silicone, polysulfide, and polyurethane. Polyurethane is also available as a high-solids fluid which solidifies in presence of humidity, which is really the second component.

9-4. Uses

Fluid-applied membranes and coatings may be used for temporary roofing; or to extend the life of an existing built-up roof. A major use of several fluid-applied coat-

ings is to protect sprayed-polyurethane foam PUF as discussed in chapter 10.

9-5. Advantages

Fluid-applied membranes and coatings conform to irregular roof surfaces with good adhesion and little waste. They provide continuous, seamless waterproofing which may include base flashing at penetrations and edges. Fluid-applied membranes and coatings (including sprayed-on polyurethane foam and its coating) can be applied in less time than required to install a built-up roof.

9-6. Disadvantages

Fluid-applied membranes and coatings depend on high-quality surface preparation. Substrate cracks must be located, marked, and either sealed or taped. Cracks and seams greater than 1/64 inch should be tilled and sealed. Sealant may shrink in cracks between 1/64 and 3/8 inch wide, and satisfactory joint filling may require two sealant applications. Cracks or joints over 3/8 inch should be filled with appropriate joint filler and then taped. Cast-in-place concrete decks must be steel-troweled and then cured for at least four weeks to reduce repairs of post-application shrinkage cracks. To prevent moisture entrapment in the fluid-applied membrane, at least 2 days should be allowed between the latest rainfall and membrane application. Fluid-applied membranes require intensive maintenance; they usually require re-coating at intervals of 2 to 7 years.

9-7. Applications

Fluid-applied membranes are suitable for use on structural concrete (cast-in-place and precast), sprayed-in-place polyurethane foam, and in special cases, plywood. (Plywood has poor dimensional stability where humidity varies substantially). Fluid applied coatings may be used on an existing membrane; sheet metal, or concrete. Coatings should be used only where the substrate provides the waterproofing.

CHAPTER 10

SPRAYED POLYURETHANE FOAM

10-1. Material description

Polyurethane foam (PUP) is a monolithic plastic foam roof insulation, produced in the field by nozzle-mixing two separate liquid streams; an “A” (isocyanate) component and a “B” (hydroxyl or polyol) component. In addition to these two basic chemical ingredients, the sprayed field mix also requires:

- a. A blowing agent (fluorocarbon gas) is included in one or both of the two liquids; these liquids react to produce heat which vaporizes the fluorocarbon to form foamed cells and expand the polyurethane foam resin’s volume;
- b. A surfactant to control cell size and cell-wall rigidity;
- c. Catalysts to control the reaction rate between the two chemical components;
- d. Fire retardants.

10-2. Uses

Sprayed polyurethane foam has its major use in reroofing. It offers the following advantages:

- a. High thermal resistance per unit thickness;
- b. Lightweight (roughly 1 psf for 3-inch thick foamed insulation with membrane coating);
- c. Fast construction (generally two to three times the rate of conventional bituminous systems);
- d. Adaptability to steeply sloped, curved, and other irregular roof surfaces;
- e. Excellent adhesion; capable of producing 3,000 psf uplift resistance when placed on a clean, dry, properly prepared substrate;
- f. Simple flashing details.
- g. The PUF system is seamless.
- h. Exterior damage is localized by the closed cell structure.
- i. Recoating will “renew” the system; some coatings are guaranteed for 10 years.

10-3. Disadvantages

Compared with conventional built-up roof systems, sprayed polyurethane foam has some offsetting disadvantages:

- a. Added cost of recoating the fluid-applied membrane periodically,
- b. Greater difficulty in obtaining a level surface and uniform insulation thickness;
- c. Extremely high dependence on applicator’s skill;
- d. High dependence on good substrate preparation;
- e. Reduced traffic and impact resistance;
- f. High vulnerability to degradation in hot, humid climates;

g. Vulnerability to bird-pecking. Once the tough outer covering is penetrated, birds will dig out the foam and will even build nests in it. (Some manufacturers will provide preventative maintenance.)

10-4. Design recommendations

Design should include substrate minimum slope of 1/4 inch per foot; and should consider wind uplift and fire resistance ratings. The design should not rely on varying foam thickness to provide slope-to-drain. At least one PUF system has been approved by the UL for use directly on steel deck; but most systems require use of a minimum 3/8 inch thick exterior-grade plywood (untreated) fastened to the deck, or for fire rated deck, a layer of perlite. Fastenings should conform with FM requirements for anchoring insulation boards.

a. *Wind-Uplift Resistance.* Well adhered sprayed polyurethane foam should satisfy the most rigorous wind-uplift forces.

b. *Fire Rating.* For most applications, fire rating should be Class A when tested by UL 790 (external exposure) and FM Class 1 (interior fire exposure).

c. *Vapor Retarder.* As required.

d. *Foam Thickness and Slope.* Thickness may be two to three inches in semi-tropical environments. Whenever possible, the deck should be sloped rather than varying the foam thickness to provide surface slope-to-drain. Slope may also be provided by installation of compatible, tapered-roof insulation as a substrate; this permits spray application of uniformly thick foam. Uniform thickness is more apt to produce consistent quality because varying the thickness requires a difficult adjusting of the spray rate to maintain a uniform chemical reaction. If slope is provided by foam, tapered boards can be used to indicate proper surface contours of the foam.

e. *Control Joints.* Area dividers should be provided at all re-entry corners, and the roof should be divided into sections of 10,000 square feet or less.

f. *Cants.* Cants should be used at all changes in direction to avoid 90 degree bends.

10-5. Membrane coatings

Polyurethane foam requires a protective membrane covering. A good membrane coating must have these properties:

- a. Good adhesion;
- b. Temperature stability (i.e., viscous at high temperature, but not brittle at low temperature);
- c. Abrasion resistance;
- d. Weather resistance (to solar radiation, rain);

- e.* Maintainability (ease of repair when damaged, integration of repaired section with original material);
- f.* Durability;
- g.* Strength and elasticity;
- h.* Low permeability in humid climates.

10-6. Application

a. Foam. For best control of foam cell size, density, and overall uniform foam quality, the polyurethane foam resins are field-sprayed to uniform thickness (1 inch minimum thickness, 3 or 4 inches maximum thickness). The foam should have an “orange peel” appearance to provide good adhesion of the coating. Manufacturers’ recommendations should be followed.

b. Coating. The coating applied to sprayed polyurethane foam should always be fluid-applied; it must fill the irregular substrate; adapt to the slightly irregular surface of sprayed foam, to the “day’s-work” termination details, and to the flashing of sprayed foam substrate. Foam applied today must be coated today. Coating should be applied in two or more coats with total minimum thickness as follows: 30 mils for silicone, 40 mils for urethane or acrylic. In hot climates urethane coating should be increased to 45 mils and acrylic coating should not be used.

10-7. Flashings

Fluid-applied flashings are generally self-sealing extensions of the membrane coating, applied simultaneously with the coating.

CHAPTER 11

STEEP ROOFING

11-1. Description

Steep roofing is considered herein as any slope which exceeds 2 inches per foot.

11-2. Function

Steep roofing is usually covered with shingles, shakes, or tiles, all of which depend on the gravitational-force component provided by slope to assure positive water-shedding. This gravitational water-shedding force must exceed all the opposing forces (kinetic, capillary, and atmospheric pressure) that tend to draw or drive water up the slope between overlapping roof units. Roll roofing, used on the lower slope ranges of steep roofing, relies relatively less on water-shedding principles and more on the water resistance provided by an underlayment. Roll roofing should be considered as a water-shedding system and not as a waterproof membrane. A slope 4 inches per foot is adequate for most steep roofing systems to assure dependable water-shedding. Lower slopes require additional measures to assure good performance.

11-3. Materials

For steep roofs, the NRCA Roofing and Waterproofing Manual lists asphalt shingles, asphalt roll roofing, clay and concrete tile, slate, and wood shingles or shakes. Some single-ply and fluid-applied membranes have also been used successfully on steep roofs. All of these materials come in varied subgroups. Details for asphalt steep roofing may be found in the ARMA Residential Asphalt Roofing Manual and the NRCA Roofing and Waterproofing Manual.

11-4. Slopes

Minimum slope should be 4 inches per foot for tile, slate or shingles unless the underlayment is sufficient to act as a membrane in which case, asphalt shingles may be used on slopes as low as 2-1/2 inches per foot and clay or concrete tile may be used in slopes as low as 2 inches per foot. In snow country, designers should consider hazards of sliding and drifting snow.

11-5. Decks

Concrete and steel decks require application of wood nailers to receive shingles. Details are provided in the NRCA Roofing and Waterproofing Manual.

11-6. Underlayment

The underlayment can keep the deck dry until shingles or tiles are installed. If the underlying wood deck gets wet and warps it will have to be replaced before the shingles can be placed. Subsequently, the underlayment provides secondary water resistance when the shingles or tiles are damaged or wind-lifted. A good underlayment can reduce leaks from wind-driven or ice-dam water which may penetrate under the overlapped shingles or tiles. Underlayment forms a cushion for slates; and prevents chemical reactions between resins in wood nailers or cants and the asphalt in shingles or roll roofing. In hurricane-damaged roofs, the underlayment often protects buildings even after shingles or tiles are blown off, while similar buildings with no underlayment and the same kind of damage are more likely to suffer extensive water damage.

a. Material. A fully-adhered modified-bitumen membrane is the preferred underlayment and should be used wherever possible, especially in cold regions for cold eaves and valleys. Modified bitumen can be used for any slope. For slopes of four inches per foot and higher, a BUR type underlayment may consist of one layer of non-perforated asphalt-saturated felt. For lesser slopes, two layers of the same felt or one layer of modified bitumen may be required. Asphalt-saturated felts should be set-in, laminated-with and coated-with Type IV asphalt or roofing cement.

b. Ice Shield. Regardless of the type of underlayment required, or the slope of the roof, in locations where the January mean temperature is 30 degrees F or less, an adhered modified bitumen membrane should be applied as the underlayment, starting from the eaves to a point 24 inches inside the interior wall line of the building to serve as a waterproof membrane in areas where ice dams may form. Where modified bitumen is not available, an alternate method uses roofing felts exposed 17 inches with a 19-inch headlap or selvedge edge and set in asphalt or roofing cement. This double felt method is the traditional treatment which has been largely supplanted by the superior modified bitumen.

c. Low Slope Wood Shake Roof. Wood shakes may be used on a roof with slope of 2 to 4 inches per foot, if a combination under- and inter-layment system is installed as described in the NRCA Steep Roofing Manual.

11-7. Ventilation

Most steep roofs contain permeable under-deck insulation. All steep roofs should contain an air barrier to

prevent leakage of indoor air up into the roof. When a vapor retarder is also needed such roofs should also be ventilated to remove moisture which will inevitably penetrate or bypass the vapor retarder. In cold regions, ventilation reduces formation of icicles and ice dams at eaves. Ventilation is easier for a steep roof than for a low slope roof.

a. Area and slope. For roof slopes greater than 2 inches per foot, the net area of ventilation openings should be at least 1/300 (i.e., 0.033%) of the area of the space to be ventilated. When the slope is 2 inches or less, the area should increase to 1/150 (i.e., 0.67%) of that area; the air space should be at least 2 inches high and cross-purlins at least 1-1/2 inch high should be placed perpendicular to the rafters before the deck is placed above. This interconnects all the individual enclosed rafter spaces to avoid dead spots where condensation will be likely. As the slope decreases below 1 inch per foot, there is little stack effect to cause a draft; ventilation is slight except during windy periods and condensation problems are likely. For this reason, when a vapor retarder is needed, low-sloped roofs should not be used with permeable below-deck insulation.

b. Vents. Vents should be located so that intakes are along the eaves and exhausts are along the ridge. Gable end vents can only be used in small buildings and they are prone to “short-circuiting” even then. Baffles or other special construction may be needed to keep vent paths clear; not only “as-built” but for the life of the building.

c. Mechanical. Natural ventilation should be used wherever practical since mechanical ventilation is expensive to install and to operate.

11-8. Anchorage techniques

a. Fasteners. Fastener requirements for different roofing materials are shown in table 11-1. For nail patterns and spacing, consult the NRCA Roofing and Waterproofing Manual, the ARMA Residential Asphalt Roofing Manual, or the ARMA Asphalt Roofing with Staples Manual. Fastener requirements for clay and concrete tile vary with slope and wind design conditions. Wiring may also be required for anchoring of ridge tiles. Fasteners must be corrosion-resistant.

b. Anchorage. In addition to fasteners, anchorage of various steep roofing materials requires other techniques. Lap cement is used at seams in asphalt roll roofing (side, end, ridge and hip strips). Asphalt shingles have self-sealing strips. Use of plastic cement is standard to secure slate units at ridges and hips.

c. Hurricane or High-wind Zones. These require additional anchorage precautions. Clay and concrete tiles should be secured with special hurricane clips, additional fastening, and additional headlap (3 inches additional in 70 to 100 miles per hour wind zones, 4 inches additional in hurricane zones of 100 plus miles per hour winds).

Table 11-1. Fasteners for Steep Roofing

Roof Material	Fastener Requirements
Asphalt Roll Roofing	No. 11 or 12 gauge hot dipped galvanized fasteners with 3/8 inch minimum heads, shank length long enough to penetrate through the roofing and deck or at least 3/4 inch into a plywood or lumber deck.
Clay or Concrete Tile	No. 11; copper, galvanized or stainless steel, shanks to penetrate minimum 3/4 inch into sheathing or through it.
Asphalt Shingles	No. 11 or 12 gauge, hot-dipped galvanized, 3/8 inch minimum heads, with shank length long enough to penetrate through the roofing and through a wood panel deck or at least 3/4 inch into a lumber deck.
Wood Shakes, Shingles	Rust-resistant, galvanized or aluminum nails, 14 gauge, 3d x 1-1/4 inch long for 16 inch and 18 inch shingles or shakes; 14 gauge, 4d x 1-1/2 inch long for 24- inch shingles or shakes.
Slate	Copper slating nails only. 3d up to 18-inch long slates, 4d for 18 inches and longer slates, 6d nails at hips and ridges. Minimum length = 2 x slate thickness + 1 (e.g., 1-1/2 inch minimum length for 1/4 inch slate).

NOTE: Staples may be substituted for nails, one-for-one, for wind- resistant shingles with factory-applied adhesives on new or recover construction. Consult ARMA Residential Asphalt Roofing Manual and individual manufacturers’ instructions. “Hot” roofs in cold regions should slope 4 inches per foot or more (with backnailing) and have eave overhangs of less than 12 inches to minimize ice dam problems. “Cold” (ventilated) roofs are preferred over “hot” (unventilated) roofs in cold regions.

11-9. Flashings

Flashings are required on steep roofs as well as low slope roofs to seal the joints at roof terminations and intersections - e.g., where roof planes intersect to form valleys, where dormers, chimneys, skylights, and other components pierce the roof, and at roof perimeters. Steep roof flashing materials and techniques are listed in the NRCA Roofing and Waterproofing Manual.

11-10. Applicable details

Further details (including flashing and ventilation) are available in the NRCA Roofing and Waterproofing Manual and SMACNA Architectural sheet Metal Manual.

CHAPTER 12

WATERPROOFING AND DAMPPROOFING

12-1. General

Waterproofing is the treatment of a surface to prevent the passage of water under hydrostatic pressure. Dampproofing is a similar treatment where membrane is only required to retard moisture penetration; to resist the "rising damp." The objectives of waterproofing design are to drain away the water and prevent the build-up of hydrostatic pressure (0.43 psi for each foot of water depth), and to provide a membrane capable of withstanding the maximum expected water pressure for the life of the building. Requirements for dampproofing are less rigorous as there is no water pressure involved.

a. For both horizontal and vertical surfaces, multi-ply bituminous or modified bitumen systems provide good waterproofing at low cost. ASTM C 981 provides bituminous built-up membrane details which can be readily adapted to modified bitumen membrane.

b. Fluid-applied and single-ply sheet waterproofing applications can be considered if conditions will not be severe and if access in case of failure is easy.

c. Bentonite clay panels are sometimes used for waterproofing, especially below slabs and on the till side of vertical walls. Bentonite must be retained in place, should be continuously wet, and not be exposed to moving water, to extremes of temperature or to certain chemical conditions. Bentonite is fragile and easily disturbed or penetrated, but it is inexpensive and effective in controlled applications.

d. Metallic oxide and cementitious waterproofings are usually limited to the interior faces of walls or floors which are below grade. Sealing the inside wall is not an effective waterproofing technique. These materials are more often used for dampproofing.

e. Membranes of butyl rubber have better water resistance and higher costs than bituminous or modified bitumen membranes. Butyl rubber can withstand ponded water in depths up to 30 feet and is often specified to protect critical facilities such as computers, libraries and hospitals.

12-2. Uses

Waterproofing may be required for floors and walls, planters, slabs, tunnels, and sidewalk vaults where water is expected. Waterproofing is frequently required for structures below grade.

12-3. Substrates

The substrate to receive water- or dampproofing must be free of laitance, curing compounds, oil, grease, and moisture in any form. The surface must provide a smooth base free of projections or cavities which could damage the waterproofing. Masonry and concrete require priming with a material that is compatible with the selected membrane system.

12-4. Membrane

The membrane should be reinforced at all joints. Reinforcing should also be applied to sharp turns, flashing terminations, penetrations, pedestals, and drains. Bituminous felt plies have been the most often used waterproofing membrane. Recommended number of plies are listed in table 12-1 for water pressures from 1 to 50 feet.

Table 12-1. Felt Plies and Asphalt for Varying Head of Water

Head Water (Ft.)	Pile of Felt and/or Fabric	Bitumen Moppings	Approx. Total lbs. of Pitch per square (1)	Approx. Total lbs. of Asphalt per square
1-3	2	3	75-98	60-75
4-10	3	4	100-120	80-100
12-25	4	5	125-150	100-125
26-50	5	6	150-180	120-150

(1) A square = 100 sq. feet. Coal-tar pitch should not be used on any surface with a slope in excess of 1/4- inch per foot.

1.2-5. Protection

Membranes above and below grade must be protected from damage during and after construction as detailed in the NRCA Roofing and Waterproofing Manual. On vertical surfaces fiberboard or insulation board (as recommended by the manufacturer) should be applied to protect the membrane during backfill operations.

12-6. Subterranean space

If the subterranean waterproofed space is to be occupied, it may need to be insulated with extruded polystyrene insulation on the outside of the waterproofing. The insulation may be required under all or part of the ground slab, and around the perimeter and the foundation wall exteriors from footings to grade line, depending on the results of a separate energy analysis.

12-7. Drain tile

Waterproofed exteriors should be blanketed with coarse rock which is underlain at foundation level with perforated drain tile connected to adequate sumps or existing storm water systems. Drain tile must be sloped to the drain connections.

12-8. Design requirements

a. Slope. All horizontal surfaces to be waterproofed should have slope of 1/4 to 1/2 inch per foot in the monolithic pour if possible. Dead level slabs should be avoided.

b. Walls. Walls may require nailers to secure the top of the membrane 6 to 8 inches above grade. Horizontal nailers should be provided at 6 foot elevation intervals, set in a bed of bituminous material and waterproofed with additional layers of fabric and bituminous cement. Plies of felt or fabric should run vertically.

c. Expansion Joints. These joints must receive preformed neoprene gaskets, properly flashed.

d. Membrane Selection. The membrane may include felts, fabric and/or coated fabric set in hot or cold bituminous material or adhesive. Table 12-1 offers guidelines for determining the number of felt and/or fabric plies and moppings needed to resist different hydrostatic pressures.

e. Lap Seams. If sheet-applied membranes, such as PVC, neoprene, butyl, EPDM, or Hypalon are selected, great care must be taken in the preparation and testing of the lap seams before covering or back filling.

f. Preformed Membranes. Factory-produced preformed membranes consist of a film of paper, polyethylene, or polyvinyl chloride, and are coated on both sides with rubberized asphalt or coal-tar pitch. The membrane manufacturer's recommended primer and adhesive should be specified.

g. Ultraviolet Protection. Some bituminous single-ply waterproofing sheet materials require ultraviolet protection and/or backfill to prevent blistering. Butyl, EPDM, PVC and CSPE membranes are resistant to UV.

h. Membrane Protection. Most waterproofing systems require protection boards placed prior to backfilling to prevent damage to the waterproofing membrane.

12-9. Dampproofing

Some situations do not require a waterproof membrane; the only requirement is to retard moisture penetration; the "rising damp." This can be accomplished with brushable or trowelable bituminous or synthetic materials; hot or cold. These materials require at least two coats of the appropriate primer when applied over masonry or concrete.

12-10. Details

Waterproofing details should conform to NRCA Roofing and Waterproofing Manual and ASTM C 981.

12-11. Plaza waterproofing

Some buildings provide large open promenade spaces with planters for aesthetics and pedestrian or vehicular traffic roof areas. Typical plaza systems and subsystems almost always contain free water, flowing in quantity. The basic system must be designed to excrete water that does get in, without damage to the interior space. ASTM C 981 provides details for design and installation of plaza decks over occupied spaces.

a. Materials. Plaza waterproofing basic membrane options include hot-applied built-up roof membrane, elastomeric sheet, and liquid-applied waterproofing. Of these three types, the hot applied built-up bituminous offers the following advantages:

- (1) Multiple lines of waterproofing defense (via alternating layers of felt and bitumen);
- (2) Adaptability to hot-applied protection boards;
- (3) Excellent adhesion to concrete substrates;
- (4) Familiarity to waterproofing mechanics;
- (5) Known performance criteria.

b. Planters. Planters are notorious leakers. Whether precast or poured-in-place, they should not interrupt the main deck waterproofing. If poured-in-place planters are selected, they must be handled as a perimeter flashing. Precast planters are recommended. Never locate a planter across an expansion joint.

c. General requirements for plaza waterproofing.

(1) *Minimum Slope.* Minimum slope should be 1/4 inch per foot, built into the base slab (1/2 in. is preferred). Pills should not be used to provide slope. Crickets may be used between drains at perimeter walls.

(2) *Joint Construction.* Design of joint construction should use the "watershed" concept in the base slab (refer

to ASTM C 981). These raised sections keep water freely drained from these very critical areas. Perimeter construction and expansion joints should be provided with appropriately shaped preformed joint formers flashed into adjoining membrane.

(3) *Vapor Retarder*. The waterproofing will act as a vapor retarder; but where the interior is very humid, and the waterproofing is cold, an additional vapor barrier may be required, and located by calculation of the vapor drive and dew point location.

(4) *Insulation*. The insulation must have low water absorption and be in sufficient thickness to maintain membrane temperature above dew point.

(5) *Waterproofing Termination*. Waterproofing should terminate 8 inches above the finish wearing surface of the plaza deck at all walls and other projections. Flashings should be applied as specified.

(6) *Flashings*. All flashings must project onto horizontal membrane a minimum 4 inches with two additional plies of stripping and terminate a minimum of 8 inches above finished grade of the plaza deck. Compatible elastomeric material should be used to provide for movement.

(7) *Counter Flashings*. Sheet metal counter flashings should be installed to protect the top seams of the flashings.

(8) *Percolation Course*. Percolation course should be 2 inches thick, below the insulation, and consist of washed smooth round river rock to drain water from insulation and to promote free flow to drains. Insulation board with preformed drainage channels is also acceptable.

(9) *Filter Fabric*. Filter fabric, applied over the percolation or insulation course will help to prevent clogging from dirt or other debris.

(10) *Pavers*. Wearing surfaces may consist of poured-in-place concrete slab surface, pavers on mortar bed, or pavers on pedestals. Pavers on pedestals are recommended for easy access in case of leaks. Bituminous wearing courses should not be used if they require rolling for compaction. Pavers must be set and elevated to allow sufficient opening between joints and substrate to filter ponded water to percolation course and into drains. Pavers should be leveled on all four corners.

(11) *Drains*. All drains must have weep holes at every sub-assembly level and be flashed into the membrane (Drain manufacturers will provide special assemblies).

(12) *Protection Boards*. Require protection boards for membrane and insulation, or both, depending on location of these components.

(13) *Testing*. Completed waterproofing should be water-tested, with special care given to flashings, expansion joints and drains where most leaks occur before additional components are added.

(14) *Overflow Drains*. Overflow drains should be as specified for low slope roofing.

(15) *Interior Gutters*. Where justified, interior metal gutters may be installed under expansion joints or skylight perimeters connected to interior drainage system.

APPENDIX A

REFERENCES

Government Publications

Code of Federal Regulations (CFR)

CFR Title 10, Chapter II, Part 435

Departments of the Army and the Air Force

TM 5-809-1/AFM 88-3, Ch. 1

TM 5-852-9/AFR 88-19, Vol. IX

Energy Conservation

Voluntary Standards for New Buildings;

Federal Buildings.

Structural Design Criteria - Loads

Arctic and Subarctic Construction Buildings

Nongovernment Publications

American Society for Testing And Materials (ASTM), 1916 Race Street, Philadelphia, PA 19103

ASTM C 981-89

Guide for Design of Built-Up Bituminous
Membrane Waterproofing Systems for
Building Decks

ASTM C 898-89

Standard Guide for Use of High Solids Content,
Cold Liquid-Applied Elastomeric Waterproofing
Membrane With Separate Wearing Course

American Society of Civil Engineers (ASCE), 345 East 47th Street, New York, NY 10017

ASCE 7-88

Minimum Design Loads for Buildings and Other
Structures (Approved December 1988, Published
July 1990)

Asphalt Roofing Manufacturers Association (ARMA), 6288 Montrose Road, Rockville, MD 20852

Asphalt Roofing With Staples Manual
Residential Asphalt Roofing Manual

Factory Mutual Engineering and Research (FM), 1151 Boston-Providence Turnpike, P.O. Box 9102, Norwood, MA 02062-9957

Approval Guide, 1992; Supplements I, II & II
Loss Prevention Data Sheet I-28,
Insulated Steel Deck, May, 1983

International Conference of Building Officials, 5630 South Workman Mill Road, Whittier, CA 90601

Uniform Building Code, 1988 Edition
Uniform Plumbing Code, 1988 Edition

National Roofing Contractors Association (NCRA), O'Hare International Center, 10255 West Higgins Road, Suite 600, Attention: Publications, Rosemont, IL 60018

The NRCA Roofing and Waterproofing Manual,
Third Edition, Copyright 1989 (includes:
The NRCA Steep Roofing Manual)

Sheet Metal & Air Conditioning Contractor's National Association (SMACNA), P.O. Box 221230, Chantilly, VA 22022-1230

Architectural Sheet Metal Manual, Fourth Edition (1987)

Single Ply Roofing Institute (SPRI) , 20 Walnut Street, Suite 208, Wellesly, MA 02181

Wind Design Guide for Single-Ply Roofing Systems

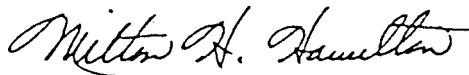
Underwriters Laboratories (UL), 333 Pfingsten Road, Northbrook, IL 60062

Building Materials Directory (1992; and Supplement)

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